Consequences of Climate Change on Agroecosystems

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Introduction

Increasing evidence over the past few decades indicate that significant changes in climate are taking place worldwide as a result of enhanced human activities. The inventions that were discovered during last few centuries, more so in the last century has altered the concentration of atmospheric constituents that lead to global warming. The major cause to climate change has been ascribed to the increased levels of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), nitrous oxides (NO_2), chlorofluorocarbons (CFCs) beyond their natural levels due to the uncontrolled activities such as burning of fossil fuels, increased use of refrigerants, and enhanced agricultural related practices. These activities accelerated the processes of climate change and increased the mean global temperatures by 0.6°C during the past 100 years, a phenomenon known as global warming. It has also induced increased climatic variability and occurrence of extreme weather events in many parts of the world. Studies indicate that the years *viz.,* 1997, 1998 and 1999 during the past century, recorded more warmer conditions across the globe, and the process continued in this decade also. Summer 2002 and 2003 were declared as warmest years on record by NOAA especially in the Asian sub continent and in Europe where the temperatures remained extremely high for long periods resulting in death of 20,000 human populations in Europe alone. Scientists attribute this to a long-term warming trend over the globe.

Climate change current Scenarios

Global

Weather observations indicated that the global average surface temperature has increased by 0.6^{o}C (IPCC, 2001) since the 19th Century. The rate of warming is faster than at any other time, during the past 100 years, which is attributed to the increase in the proportion of carbon dioxide and other greenhouse gases in the atmosphere over the last century. Observations also indicated that all the warmest years during the past century across the globe occurred in the last 2 decades (1981-1990 and 1991-2000). Among these years, 1998 was the warmest year on record (IPCC, 2001). Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change.

The atmospheric concentration of carbon dioxide has been increasing at an alarming rate (1.9 ppm per year) in recent years than the natural growth-rate. The global atmospheric concentration of methane was at 1774 ppb in 2005 and nearly constant for a period of time. Nitrous oxide increased to 319 ppb in 2005 from pre-industrial value of about 270 ppb. Thus warming of climate system is unequivocal, as it is evident from the recent past that eleven warmest years occurred during 1995-2005. The increase in mean air temperature over the globe fore the last 100 years (1850-1899 to 2001-2005) is 0.76°C which is influencing the reduction of snow cover and discharge of river water in addition affecting the agricultural production system. The Fourth Assessment report of Intergovernmental Panel on Climate Change (2007) concluded that 'there is high confidence that recent regional changes in temperature have had discernible impacts on many physical and biological systems'.

India

- The monsoon rainfall at All India level does not show any trend and is random in nature over a long period of time.

- The presence of pockets of significant long-term changes in rainfall has been recorded.

- Areas of increasing trend in monsoon rainfall are found along the west coast, north Andhra Pradesh and north-west India and those of decreasing trend over east Madhya Pradesh and adjoining areas, north-east India and parts of Gujarat and Kerala (-6 to -8% of normal over 100 years).

- Surface air temperature for the period 1901-2000 indicated a significant warming of 0.4°C for 100 years.

- The spatial distribution of temperature changes indicated a significant warming trend has been observed along the west coast, central India, and interior Peninsula and over northeast India. However, cooling trend has been observed in northwest and some parts in southern India.

- Instrumental records over the past 130 years do not show any significant long-term trend in the frequencies of large-scale droughts or floods in the summer monsoon season.
- The only change is the alternating sequence of multi-decadal periods of more frequent droughts followed by periods of less frequent droughts.

- The total frequency of cyclonic storms that form over Bay Bengal has remained almost constant over the period 1887-1997. However, the frequency of severe cyclonic storms appears to have taken place in the recent decades.

- A slight decrease in trend in the frequency of cyclonic disturbances is apparent during the monsoon season.

- The model-simulated data shows a balance between simulated and observed extreme maximum temperatures in the peninsular regions. However, the model underestimates high temperature estimates in the mountainous regions of Kashmir, Sikkim, Arunachal Pradesh and overestimates by 5°C over northern place.

Projected Climate Change Scenarios for India

The climate change scenarios for the Indian subcontinent as inferred by Lal *et al*. (2001) from simulation experiments using atmosphere-ocean GCMs under the four SRES marker scenarios are presented below. These results suggest an annual mean area-averaged surface warming over the Indian subcontinent to range between 3.5 and 5.5°C over the region by 2080s. These projections showed more warming in winter season over summer monsoon. The spatial distribution of surface warming suggests a mean annual rise in surface temperatures in north India by 3°C or more by 2050. The study also suggests that during winter the surface mean air temperature could rise by 3°C in northern and central parts while it would rise by 2°C in southern parts by 2050. In case of rainfall, a

marginal increase of 7 to 10 percent in annual rainfall is projected over the sub-continent by the year 2080. However, the study suggest a fall in rainfall by 5 to 25% in winter while it would be 10 to 15% increase in summer monsoon rainfall over the country. It was also reported that the date of onset of summer monsoon over India could become more variable in future.

Year	Season	Temperature Change (^{o}C)		Rainfall Change (%)	
		Lowest	Highest	Lowest	Highest
2020s	Annual	1.00	1.41	2.16	5.97
	Rabi	1.08	1.54	-1.95	4.36
	Kharif	0.87	1.17	1.81	5.10
2050s	Annual	2.23	2.87	5.36	9.34
	Rabi	2.54	3.18	-9.22	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Annual	3.53	5.55	7.48	9.90
	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

(Source: Lal et al., 2001)

Impacts of Climate Change on Various Sectors

Warming of the climate system is unequivocal and is evident from the observations of increase in air temperature, melting of snow from snow clad mountains and rising global mean sea level. These changes have profound influence on various sectors, *viz*., water resources, agriculture, land use, coastal ecosystem, livestock and fisheries in many ways. The likely impacts on these systems are briefly given below.

Agriculture

With rapid increase in population and urbanization, the availability of arable land dwindled considerably from 0.48 ha in 1950 to 0.15 ha in 200 and is likely to further reduce to 0.08 ha by 2020 (Mall *et al*, 2007). In the climate change scenario, the impacts on agricultural production are likely to be manifolds and the magnitude varies greatly by the region.

- Eastern region in the country is predicted to be most affected by increased air temperature.
- Major shifts in cropping pattern are expected to take place and the area under *rabi* crops are likely to be reduced and may move towards north.

- Reduction in crop yields is more likely in the rainfed areas due to changes in rainfall pattern during monsoon season.

- Although, increased levels of Co_2 may increase net primary productivity of plants, the changes in temperature associated with the above phenomena may nullify the benefit.

- Potential yields of major cereals crops are likely to be reduced due to likely increase in temperature.

- Major pulses pigeonpea in *kharif* and chickpea in *rabi* sorghum are to be decreased.

Direct Effects on Crop Growth and Yield

Some of the simulation model studies explain the following points

- Most of the simulation studies have shown a decrease in the duration and yield of crops as temperature increased in different parts of India.

- Yields of both *kharif* and *rabi* crops decreased as temperature increased; a 2°C increase resulted in 15-17 per cent decrease in the grain yield of both crops, but beyond that the decrease was very high in wheat.

- Since, there is greater probability of increase in temperature in *rabi,* it is likely that the productivity of wheat and other *rabi* crops would be significantly reduced.

- Wheat yields in central India are likely to suffer by up to 2 per cent in the pessimistic scenario but there is also a possibility that these might improve by 6 per cent if the global change is optimistic

- Sorghum, being a C_4 plant, does not show any significant response to increase in CO_2 and hence the different scenarios do not affect its yield.

- However, if the temperature increases are higher, western India may experience some negative effect on productivity due to reduced crop durations.

- The impact of warming scenarios becomes apparent at higher levels of fertilizer application from 2030 onwards.

- In future, therefore, much higher levels of fertilizer may need to be applied to meet the increasing demand for food.

- The production of fruits may be significantly affected if the changes in climate happen to coincide with the critical periods. Global warming will push the snow line higher and dense vegetation will shift upwards. This shift will be selective and species specific due to the differential response of plants to changing environmental conditions.

- The nutritional quality of cereals and pulses may also be moderately affected which, in turn, will have consequences for our nutritional security.

- The loss in farm-level net revenue may range between 9 per cent and 25 per cent for a temperature rise of 2-3.5°C.

Crop-Pest Interactions

- The change in climate may bring about changes in population dynamics, growth and distribution of insects and pests.

- Changes in rainfall, temperature and wind speed pattern may influence the migratory behaviour of the locust.

- Most crops have C_3 photosynthesis (responsive to $C0_2$), while many weeds are C_4 plants (non-responsive to CO_2). The climate change characterized by higher CO_2 concentration will favour crop growth over weeds.

Irrigation Water Availability

Retreat of Himalayan Glaciers

The glaciers and the snowfields in the Himalayas are on the decline as a result of climate variability. The rate of retreat of the snow of Gangotri glacier demonstrated a sharp rise in the first half of the 20th century. This trend continued up to around the 1970s, and subsequently there has been a gradual decline in its rate of retreat. The diminishing rate of retreat of the snout of the Gangotri glacier could be a consequence of the diminishing rate of rise in the temperatures.

Although the warming processes continue unabated, the rate of rise in temperatures in the Gangotri glacier area has nevertheless demonstrated a marked gradual decline since the last quarter of the past century. However, Samudra Tapu, one of largest glaciers in Chandra Basin in Lahul and Spiti receded by 862 m between 1963 and 2006, at a rate of 18.5 m in a year, with the rapid rate retreat being observed during past six years compared to earlier decades (India Today, 2006).

Glaciers in the Himalayan mountain ranges will retreat further, as temperatures increase: they have already retreated by 67% in the last decade. Glacial melt would lead to increased summer river flow and floods over the next few decades, followed by a serious reduction in flows thereafter.

The SWAT Water Balance Model has been used to assess the water availability at river basin level under projected climate change scenario with an assumption that land use will not change over time. It was observed that the impacts are different in different catchments with the following observations:

- The projected climate change will disturb the water balance in different parts of India and the quality of groundwater along the coastal track will be more affected.

- Increase in projected extreme rainfall events in major river basin of Ganga, Godavari, Krishna, Mahanadi, Brahmani, has not shown increased runoff for all the above basins perhaps due to increase in evapotranspiration on account of increased temperature.

- The surface water availability in Ganga, Godavari and Krishna showed a general increase.

- The glaciers and the snowfields in the Himalayas will decline.

- Temperature increase associated with global warming will increase the rate of snow melting and consequently snow cover will decrease.
- In the short term, this may increase water flow in many rivers that, in turn, may lead to increased frequency of floods, especially in those systems where water carrying capacity has decreased due to sedimentation.
- In the long run, however, a receding snow line would result in reduced water flow in rivers.
- Under the climate change scenario, the onset of the summer monsoon over India is projected to be delayed and often uncertain.
- This will have a direct effect not only on the rainfed crops, but water storage will also be affected, placing stress on the irrigation water.
- Since the availability of water for agriculture would have to face tremendous competition for other uses of water, agriculture would come under greater strain in future.

Soil Processes

- Changes in precipitation patterns and amount, and temperature can influence soil water content, run-off and erosion, workability, temperature, salinization, biodiversity, and organic carbon and nitrogen content.
- Changes in soil water induced by global climate change may affect all soil processes and ultimately, crop growth.
- An increase in temperature would also lead to increased evapotranspiration, which may result in the lowering of the groundwater table at some places.
- Increased temperature coupled with reduced rainfall may lead to upward water movement, leading to accumulation of salts in upper soil layers.
- A rise in sea level associated with increased temperature may lead to salt-water ingression in the coastal lands, making them unsuitable for conventional agriculture.
- An increase of 1°C in the soil temperature may lead to higher mineralization but N availability for crop growth may still decrease due to increased gaseous losses.

Implications of Climate Change on Water Availability

- The preliminary assessment has revealed that under the GHG scenario, the severity of droughts and intensity of floods in various parts of India is projected to increase.
- There is a general reduction in the quantity of the available run-off under the GHG scenario.
- Luni, the west flowing river of Kutchh and Saurastra occupying about one-fourths of the area of Gujarat and 60 per cent of the area of Rajasthan are likely to experience acute physical water scarce Conditions.

- The river basins of Mahi, Pennar, Sabarmati and Tapi are likely to experience constant water scarcities and shortage. The river basins of Cauvery, Ganga, Narmada and Krishna are likely to experience seasonal or regular water-stressed conditions.

- The river basins of the Godavari. Brahmani and Mahanadi are projected to experience water shortages only in a few locations.

Possible Effects of Climate Change on Ground Water:

- It is apparent that the projected climate change leading to global warming, sea-level rise and melting of glaciers will disturb the water balance in different parts of India and quality of ground water along the coastal track.

- Changes in precipitation and evapotranspiration may influence ground water recharge

- Rising sea levels may lead to increased saline intrusion of coastal and island aquifers

- Increased rainfall intensity may lead to higher run-off and less recharge; and

- Increased flood events may affect groundwater quality in alluvial aquifers.

Socio-economic Impacts due to Shifts in Major Forest Types

- Nearly 200,000 villages in India are situated in or on the fringe of forests.

- Further, about 200 million people depend on forests for their livelihood, directly or indirectly. Forest ecosystems in India are already subjected to socio-economic pressures leading to forest degradation and loss, with adverse impacts on the livelihoods of forest dependent communities.

- Climate change will be an additional pressure on forests, affecting biodiversity as well as biomass production. According to the assessment of projected climate impacts on forests, significant changes in the forest boundary of different forest biomes as well as biodiversity are projected.

- However, during the transient phase, large-scale forest dieback may occur. This may affect the production and supply of non-timber forest products to the forest dependent communities, affecting their livelihoods.

- In the transient phase, there could be an increased supply of timber, due to forest dieback, depreciating timber prices.

Climate-related Coastal Hazards— Future Scenario

- The past observations on the mean sea level along the Indian coast show a long-term rising trend of about 1.0 mm/year.

- However, the recent data suggests a rising trend of 2.5 mm/year in the sea level along Indian coastline.

- Model simulation studies, based on an ensemble of four AOGCM outputs, indicate that the oceanic region adjoining the Indian subcontinent is likely to warm at its surface by about 1.5-2.0°C by the middle of this century and by about 2.5-3.5°C by the end of the century.

- The corresponding thermal expansion, related sea-level rise is expected to be between 15 cm and 38cm by the middle of this century and between 46 cm and 59 cm by the end of the century.

- A one-meter sea level rise is projected to displace approximately 7.1 million people in India, and about 5,764 km2 of land area will be lost, along with 4,200 km of roads.

- An increase in the frequency of severe cyclonic storms is likely under the climate change scenario; this may enhance the vulnerability of those districts that are already ranked as vulnerable under the current climate scenario.

Climate Change and World Food Security

Climate change over the long-term, in particular global warming, could affect agriculture in a number of ways the majority of which would threaten food security for the world's most vulnerable people:

- The success rate of predictability of weather and climate would decrease, thus making planning of farm operations more difficult.

- Climate variability at regional scale might increase, putting additional stress on fragile farming systems.

- Weather extremes - which are very difficult to plan for - might become more frequent.
- The sea level would rise, threatening submergence of valuable coastal agricultural land, particularly in low-lying small islands.

- Biological diversity would be reduced in some of the world's most fragile environments, such as mangroves and tropical forests.

- Climatic and agro-ecological zones would shift, forcing farmers to adapt, as well as threatening natural vegetation and fauna.

- The imbalance of food production between cool and temperate climates tropical and subtropical regions could worsen.

- Distribution and quantities of fish and seafoods could change dramatically, wreaking havoc in established national fishery activities.

- Pests and vector-borne diseases would spread into new regions where they were previously not known.

Forests

Impact assessment of climate change on vegetation was carried out using BIOME-3 model. The output of the model

- A large-scale change in vegetative types is expected to take place that may lead to large scale mortality and forest destruction and loss of bio-diversity especially in the transition belt.

- The northwest region of the country is likely to witness increased mortality in the existing vegetation, which may lead to decrease in standing stock.

Natural Ecosystems

- Coastal wetlands have serious consequences due to climate change for the livelihoods of the people as well as the integrity of the coastal environment.

- The composition of plant species in the mangrove wetlands gets affected due to increased flows of fresh water (due to glacial melt in Himalayas) and increased salinity due to increase in local temperature and reduced precipitation.

- Increase in sea surface temperature results in bleaching of corals and may result in death.

Fisheries and Aquaculture

The increase in sea surface temperature (SST) and rise in sea level, the marine life gets affected considerably. Similarly, the inland aquaculture also affected.

- Impacts would affect the capture, production and marketing costs, loss of infrastructure fishing tools and housing.

- Migration of different marine species to favourable climate regions.

- In general temperature changes are likely to impact cool water species negatively, warm water species positively.

Energy

- A major energy demand is expected to be for space cooling and heating and transportation.

- Saving in heating energy is expected in winter due to increased temperatures in northern mountainous regions. However, this will be more than compensated by the increased energy requirements for space cooling in plains.

- Higher demand of energy for irrigation due to increased crop water requirements.

Thus the study of understanding of the issues related to climate change in addition to the climate parameters over a region are relevant with reference to various sectors in view of the imminent signals that has reconfirmed that global warming trends. These shall help in developing adaptation strategies to face the challenges posed by climate change.